Directed Flow of Protons and Anti-Protons in RHIC Beam Energy Scan II by STAR

RHIC 25: A quarter century of discovery
May 20-23, 2025

E. Duckworth (educkwor@kent.edu), Kent State University, *for the STAR Collaboration*

Abstract

Directed flow of particles is a sensitive probe of the equation of state (EoS) of the matter produced in heavy-ion collisions and could be a sensitive probe of the softening of the EoS associated with a first order phase transition according to model calculations. Directed flow of protons and anti-protons are also of interest as they offer sensitivity to both the contributions from the transported quarks and also the medium generated component from the produced quarks. Measurements of proton and net proton directed flow from BES-I have shown that there is a non-monotonous dependence on collision energy. We will present measurements of the directed flow of protons and anti-protons from the collision energies of 7.7, 9.2, 11.5, 14.5, 17.3, 19.6, and 27 GeV Au+Au collisions, using high statistics BES-II data from STAR. We will also present a decomposition of proton directed flow into a medium generated component and an excess component (v_1 excess) attributed to transported protons. The v_1 excess component is found to show a simple scaling from a center of mass energy of 200 GeV to ~10 GeV, but to break scaling below 10 GeV. The new results have significantly reduced uncertainties compared to those from BES-I and also allow differential measurements in centrality and transverse momentum. Measurements will be compared to different model calculations and implications to the understanding of the QCD phase structure and EoS of the medium will be discussed.

Motivation

dv_1/dy of protons and net protons at mid-rapidity exhibit non-monotonic behavior as a function of collision energy [3].

$$N_p v_{1,p} = N_{\bar{p}} v_{1,\bar{p}} + (N_p - N_{\bar{p}}) v_{1,net}$$

Alternatively, we can look at excess proton v_1 to better understand the origin of the proton v_1 and its beam energy dependence.

$$N_p v_{1,p} = N_p v_{1,\bar{p}} + (N_p - N_{\bar{p}}) v_{1,excess}$$

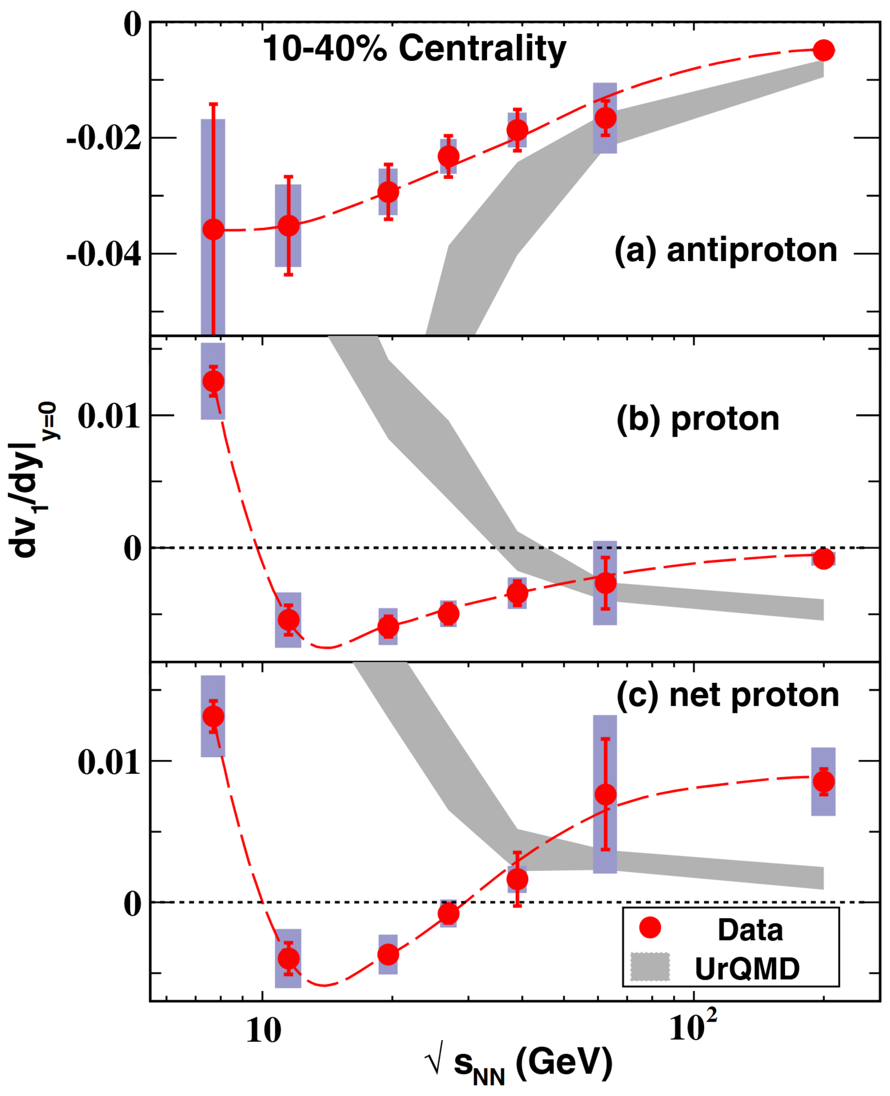


Figure 1: BES-I proton, anti-proton and net proton directed flow results.

Particle Identification

Protons and anti-protons were identified using both dE/dx and Time of Flight (TOF). Tracks with dE/dx less than 3σ away from expected value, and a TOF measured mass of $0.8 < m^2 < 1.0$ GeV^2 were identified as protons.

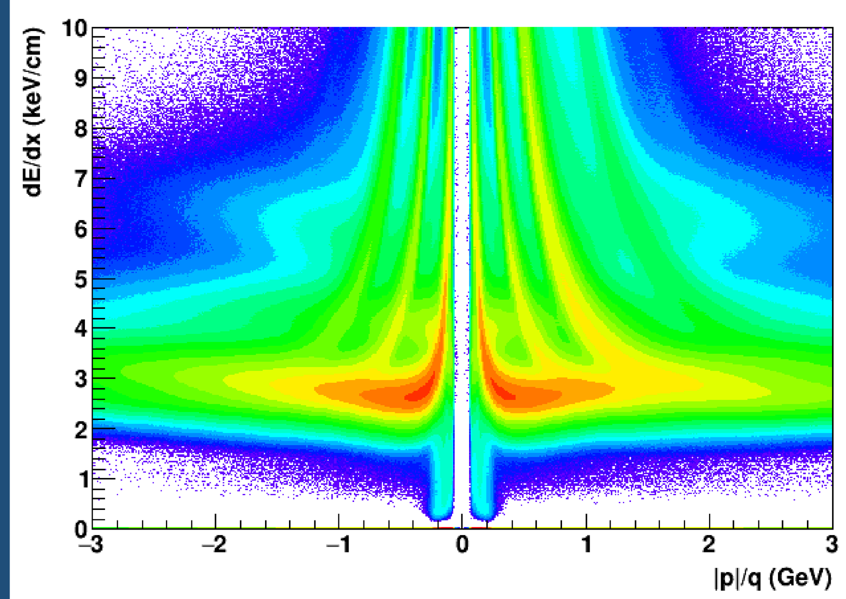


Figure 2: Momentum and dE/dx distribution of particles in 14.6 GeV Au+Au Collisions.

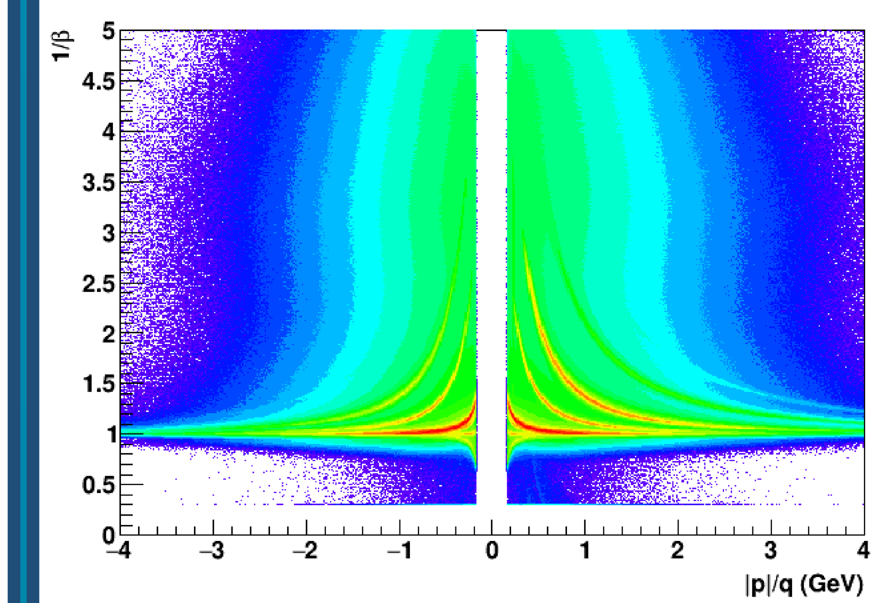
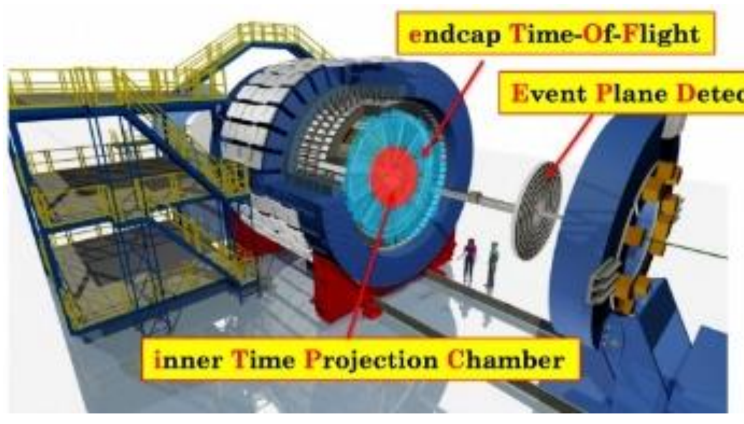


Figure 3: Momentum and β^{-1} distribution of particles in 14.6 GeV Au+Au Collisions.

Event Plane



The event plane is measured by the Event Plane Detector (EPD) [1] based on number of Minimally Ionizing Particles (nMIP). The event plane was recentered and flattened to correct for detector biases causing non uniform distributions [2]. Eta weighting of the EPD nMIP was also used due to the sign change of the Q vector in the region of the EPD.

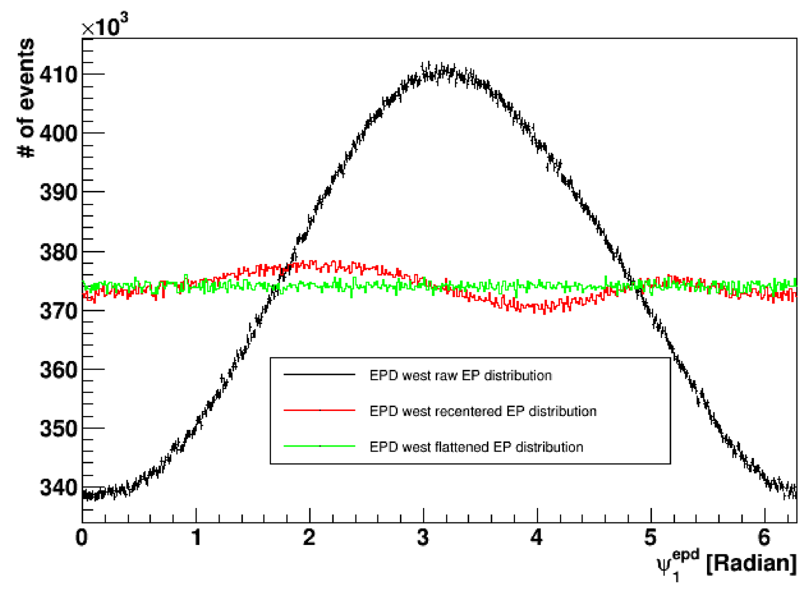


Figure 4: Raw, recentered, and flattened event plane distribution for the west EPD with 14.6 GeV Au+Au collisions.

The event plane resolution was greatly improved from BES-I to BES-II due to the installation of the EPD. This allows for a more accurate v_1 measurement, improving by a factor of 1.75 at mid-centrality

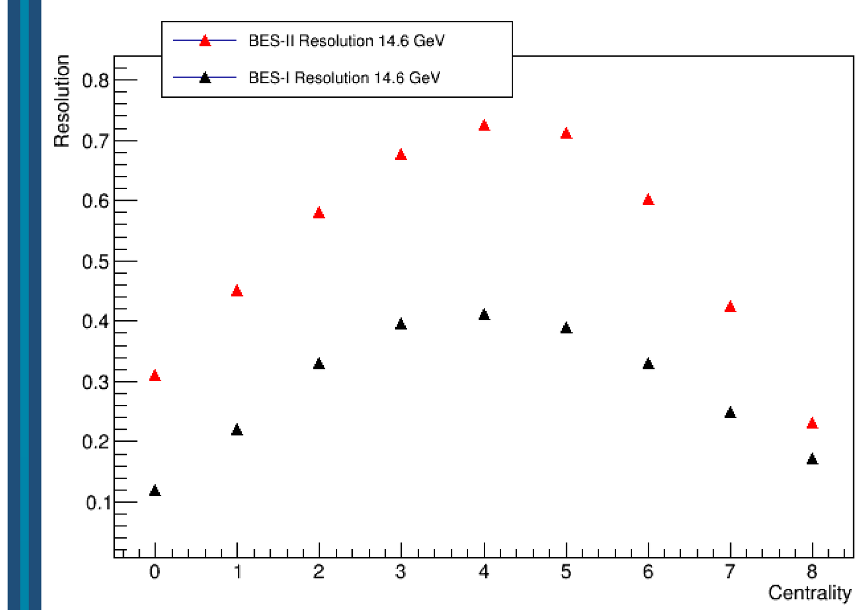


Figure 5: Resolution as a function of centrality for BES-I and BES-II 14.6 GeV Au+Au collisions.

Proton and Anti-Proton v_1 as a Function of Rapidity

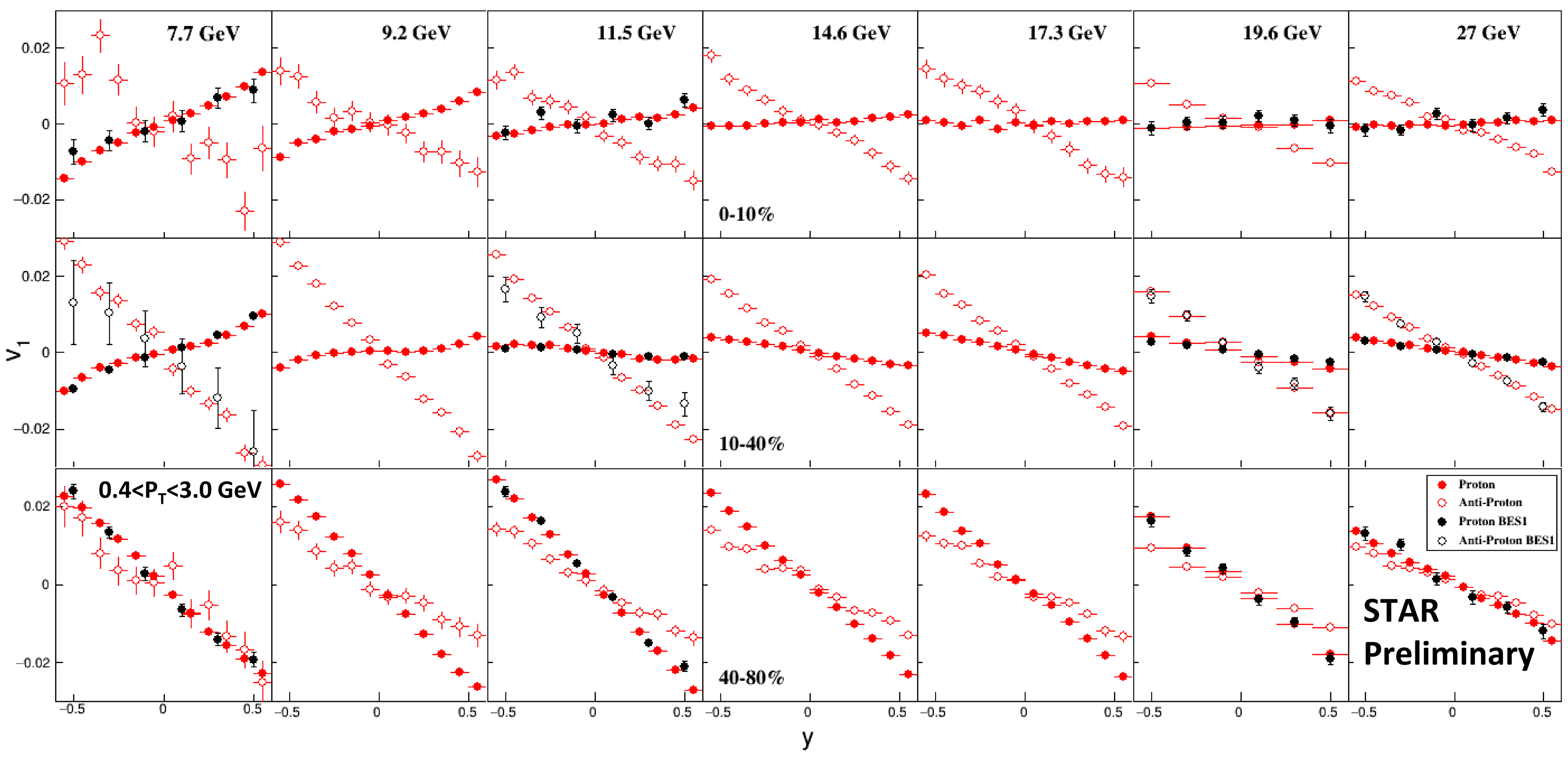


Figure 6: Proton and anti-proton directed flow as a function of rapidity for BES-II. Comparisons with BES-I are shown where available.

Summary

Excess v_1 scales with beam rapidity from 200 GeV down to 14.6 GeV. Extending to lower energies, there is clear breaking of scaling, indicating a change in medium and collision dynamics. The JAM models [4] fail to show the scaling behavior above 14.6 GeV, and overpredict the data below 14.6 GeV. Adding in momentum dependence to the potential increases the overprediction of the slope.

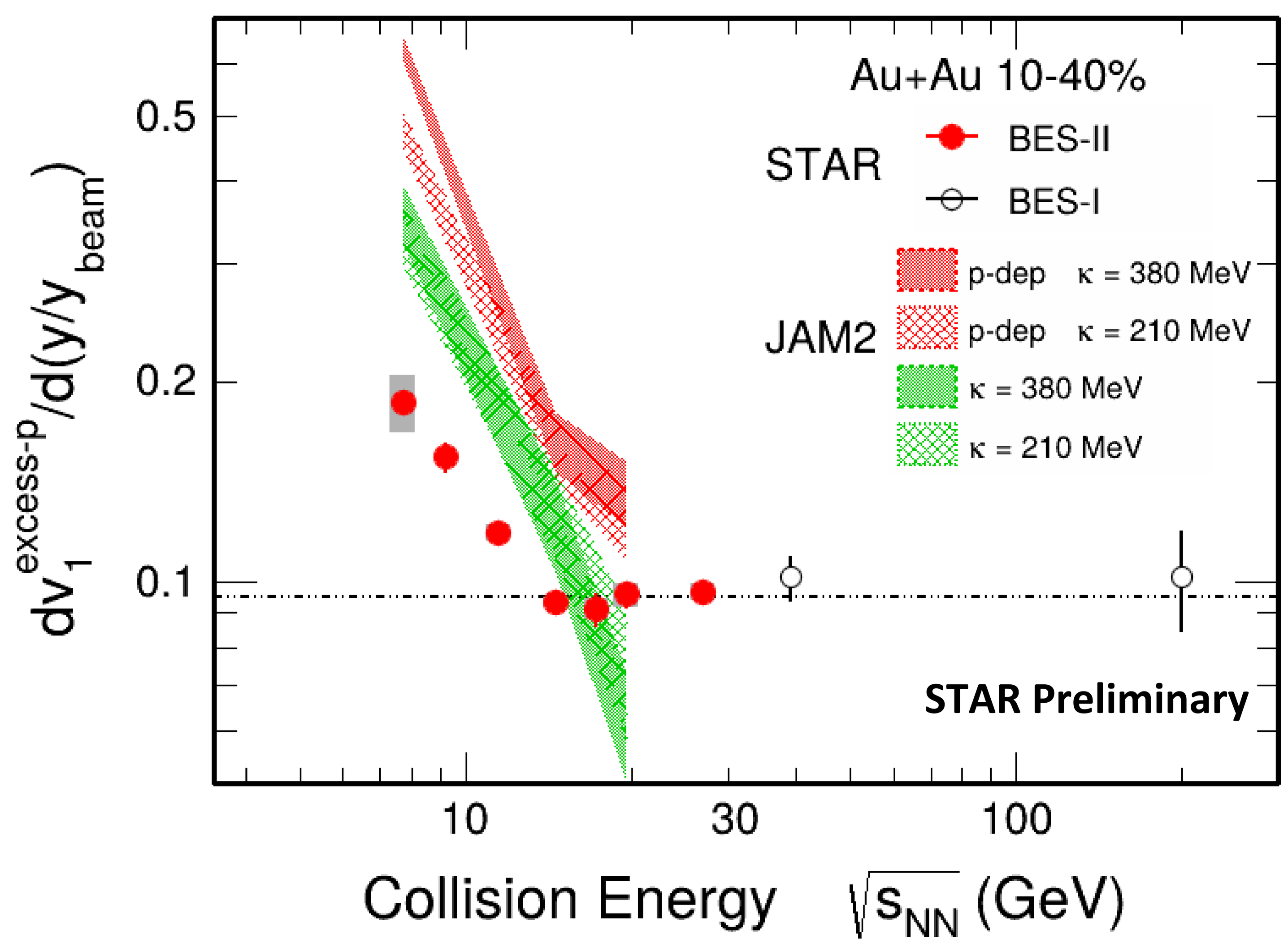


Figure 7: Beam normalized excess proton directed flow slope as a function of collision energy.

References

[1]J. Adams et al., Nucl. Instrum. Meth. A 968 (2020) 163970
[2]A. Poskanzer & S. Voloshin, Phys. Rev. C 58 (1998) 1671
[3]STAR Collaboration, Phys. Rev. Lett. 120 (2018) 62301
[4]Y. Nara et al. Phys. Rev. C 100, 054902 (2019)

Supported in part by the U.S. Department of Energy Office of Science

Kent State University

The STAR Collaboration
https://drupal.star.bnl.gov/STAR/presentations